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MATERIALS BASED ON BASALTS FROM THE EUROPEAN NORTH OF RUSSIA

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The texture and chemical composition of certain basalt varieties from the European North of Russia are investigated. The possibility of producing fine staple and continuous basalt fiber is demonstrated. Technological schemes of producing materials based on these fibers are considered. Financial and economic parameters for setting up production of basalt fibers and respective products are given.

The territory of Russia currently counts nearly 120 developed deposits of basalt and other rocks of volcanic origin similar to basalt: basalite, amphibolite, diabase, and porphyrite. The basalt and mineral rocks of Karelia, Kola Peninsula, and the Republic of Komi in the European north of Russia are known and widely used in practice.

A large deposit of basalt called Myandukha is located in Plesetk District, Arkhangelsk region. Its surveyed resources are estimated at 144.3 mln m^3. A factory for producing basalt gravel of capacity 3 mln m^3 is being constructed there. Transport communications are available nearby: Navolok railway station of the Northern Railroad is 12 km from the deposit, and Arkhangelsk – St. Petersburg motorway is 50 km from there. A quarry is in operation, and a mobile crushing-and-sorting plant of a capacity of 1000 thousand m^3 gravel per year is in operation.

The performed research indicated the suitability of using basalt from the Myandukha deposit as a raw material in the production of staple fiber. Visually the samples represent dense, fresh, and strong effusive vitreous rocks of dark gray color, without visible porphyry inclusions and amygdules. Occasionally thin veins (3 – 9 mm) are found, mainly of carbonate composition. The rock texture is massive and, extremely rarely, brecciated.

Microscopic studies identified a vitrophyric structure of the rock with a hyalite structure of the main bulk. The rock represents a basalt consisting of grayish-brown glass (30 – 40 vol.%) containing thin laths of modified plagioclase. Olivines, which are present in basalt in the form of porphyry inclusions are completely replaced by secondary serpentine and small grains of metallic minerals, and only the grain shape typical of olivine is preserved. Occasional thin veins (fractions of a millimeter) composed of quartz and carbonate are found in the rock.

The chemical compositions of the basalt rocks from the Myandukha and Kondopoga deposits were determined by the classical weight method, as well as by using x-ray spectral microprobe analysis (Table 1). For reference purposes, Table 1 also shows the chemical compositions of the basalt from the Berestovetskoe deposit (Ukraine) and Marneul'skoe deposit (Georgia), which is used in fiber production. The Berestovetskoe basalt is suitable for producing staple (superfine; fine) basalt fiber (BF), and the Marneul'skoe basalt is used for continuous and coarse BF. Table 1 also indicates the acidity modulus M_a and the viscosity modulus M_v calculated according to the formulae:

$$M_a = \frac{m_{SiO_2} + m_{Al_2O_3}}{m_{CaO} + m_{MgO}};$$

$$M_v = \frac{x_{SiO_2} + x_{Al_2O_3}}{2x_{Fe_2O_3} + x_{FeO} + x_{CaO} + x_{MgO} + x_{K_2O} + x_{Na_2O}},$$

where m is the mass content of oxides, %; x is the molar content of oxides in mineral rocks, %.

The high content of CaO and MgO in the basalt from the Myandukha deposit increases its crystallizing capacity. A

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TABLE 1

Deposit	Mass content, %														Modulus	
	SiO_2	Al_2O_3	CaO	MgO	Fe_2O_3	FeO	K_2O	Na_2O	TiO_2	MnO	SO_x	P_2O_5	CO_2	H_2O	acidity	viscosity
Myandukha	50.42	11.82	8.84	10.58	2.82	9.43	0.52	2.00	1.04	0.18	0.03	0.21	0.31	0.08	3.20	1.72
Kondopoga	53.54	14.12	6.60	6.70	2.80	7.64	1.04	3.80	1.52	0.20	0.02	0.25	0.22	0.08	5.09	2.34
Berestovetskoe	49.03	12.58	9.53	5.47	3.88	10.15	0.66	2.34	2.85	0.32	Traces	0.30	0.21	0.75	4.11	1.97
Marneul'skoe	50.61	16.75	9.07	4.65	6.66	3.60	1.00	3.88	1.81	0.18	The same	0.40	0.24	0.31	4.91	2.42

TABLE 2

Parameter	Fiber			Wool		Mats		Panels		Cords		Fabric		Plastics	
	basalt	glass	kaolin	basalt	glass	basalt	glass	basalt	glass	basalt	glass	basalt	glass	basalt	glass
Density, kg/m^3	2600	2500	2700	55 – 80	60 – 100	35 – 80	40 – 105	60 – 150	70 – 120	up to 2200	up to 2100	2.3 – 13.0*	5.5 – 11.0*	1900	2000
Limiting application temperature, °C	900	450	600	900	450	900	450	1000	450	900	450	900	450	1000	450
Thermal conductivity, $W/(m \cdot K)$	0.034	0.046	0.040	0.035	0.046	0.035	0.044	0.030	0.047	0.035	0.044	0.035	0.044	0.550	0.750
Strength, MPa	1200	800	1400	–	–	–	–	–	–	70**	60**	6200**	3000**	up to 1380	1200
Moisture absorption, %	< 1	up to 30	1	< 1	30	0.5	22	< 0.05	22	0.5	22	0.5	22	0.005	0.5
Price, USD per kg	2.5	3.5	10.0	2.5	3.5	2.7	3.75	3.0	4.2	3.0	4.2	2.8	3.9	3.0	4.2

* Filaments per cm^2.

** Breaking load, N.

smaller content of Al_2O_3 and a similar content of SiO_2 decrease the values of the modules. Therefore, the viscosity of that basalt melt should be lower than that of the Berestovetskoe basalt, which points to the possibility of producing fine staple BF with a small diameter. The studies revealed that the basalt from the Myandukha deposit melts at temperatures up to 1450°C, forming a homogenous low-viscosity melt. This makes it possible to recommend it as a single-component material in the production of fine staple fiber, using the vertical blow method employing air or steam.

The Kondopoga basalt, which has high acidity and viscosity parameters due to a low content of CaO and MgO and a high content of SiO_2 and Al_2O_3, is suitable for the production of continuous BF and roving. This material is no worse than the Marneul'skoe basalt rock.

Along with the transitional use of basalt as construction gravel, materials made on the basis of BF are attracting increasing attention both in Russia and abroad. This is due to the availability and wide occurrence of the initial raw material, as well as the simplicity of the production technology, which makes the products relatively inexpensive. The main advantages of the produced materials consist in their high thermophysical, mechanical, and corrosion-resistant parameters (Table 2).

First of all, BF exceeds mineral and glass fiber in heat resistance. The temperature interval of application of BF ranges from – 270 to 700 – 900°C, in contrast to glass fiber (– 60 to 450°C) or mineral fiber (– 50 to 600°C). In addition to the physicochemical advantages of basalt-fiber products, their cost advantages are obvious as well. It can be seen in Table 2 that BF and the products made of them surpass the analogous products made of glass fiber in all parameters.

Numerous materials based staple (diameter from 0.6 μm), coarse (300 – 500 μm), and continuous (5 – 15 μm) BF have been developed and call for intensive application in various sectors of economics.

BF serves as the basis for a wide range of heat-insulating, filtering, and other materials, which have several advantages as compared to similar products made of glass, asbestos, etc. These advantages include the absence of a carcinogenic effect, environmental cleanliness, high chemical and fire resistance, optimal thermophysical parameters, and radio transmittance. The following products can be mentioned: heat-insulating and soundproof mats based on BF 1 – 3 μm in diameter used in various devices; heat-insulating hydrophobic soft panels based on superfine BF to cover surfaces operating in the temperature interval from – 270 to 750°C; heat-insulating and soundproof cords; cables; canvases; cardboard; paper; roving; basalt plastics; basalt-plastic rods and fittings; hardening fillers for cement concrete; filter; etc.

The constantly expanding application areas determine the increasing range of basalt fiber products, at least abroad.

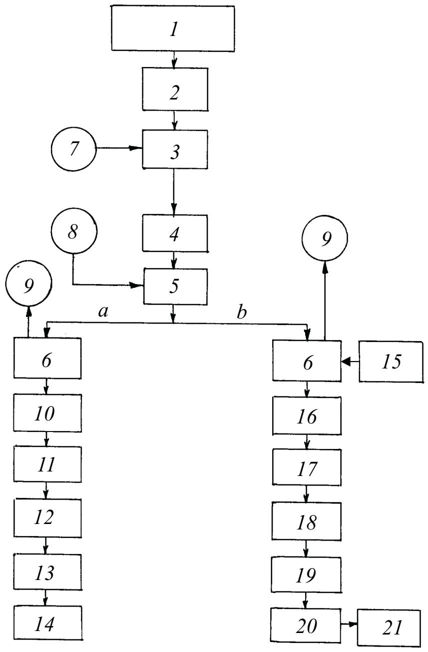

Fig. 1. Scheme of producing staple BF, mats based on BF (*a*), and panels (*b*) using binders: *1*) basalt gravel hopper; *2*) melting tank; *3*) blow nozzle; *4*) diffuser; *5*) centrifuge; *6*) fiber sedimentation chamber; *7*) high-pressure fan; *8*) lower-pressure fan; *9*) suction fan; *10*) rug formation unit; *11*) broaching mechanism; *12*) lateral cutter; *13*) packaging site; *14*) warehouse; *15*) binder feeding unit; *16*) rug formation unit with heat-treatment chamber; *17*) additional compression unit; *18*) chilling site; *19*) longitudinal and lateral saws; *20*) packaging site; *21*) warehouse.

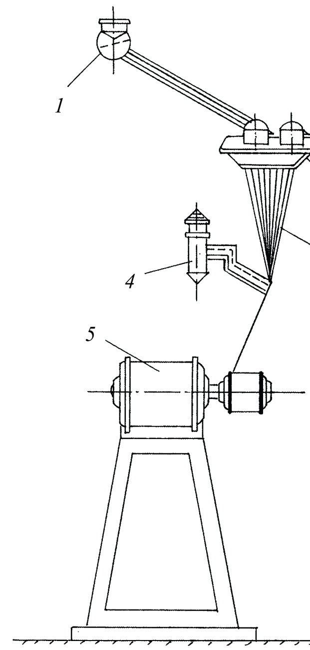

Fig. 2. Scheme of producing roving from continuous BF: *1*) basalt gravel hopper; *2*) melting tank equipped with jet and spinneret platinum-rhodium feeders; *3*) collector of elementary filaments in strands; *4*) lubricant unit; *5*) unit for winding roving on spools.

Basalt fiber is used as filler, insulating insert in laminar partitions, elastic layer in floating floors, heat- and sound-insulating material in various devices, cabins, and enclosing structures. The use of wall panels containing a BF-based heat-insulating layer in construction makes it possible to decrease the wall thickness by the factor of 2.5 and the weight of 1 m^3 of the wall to one-fifth. Comparing the wall panels containing the basalt-fiber insulator to the traditional clay brickwork, the results appear even more convincing: the wall thickness becomes 5.5 times lower; and the labor consumption is decreased 2.8 times.

Basalt fiber panels based on inexpensive, environmentally safe binders are recommended as heat insulation for doors, exterior and interior walls, concrete foundations, etc. Mats and cords based on BF can be used to heat-insulate pipelines, ventilation flues, boilers, as well as for fire protection and sound insulation at elevated temperatures (the sound absorption of basalt fiber mats reaches 82% at frequency 1800 Hz, against 60% in glass fiber mats). Any required shape can be imparted to basalt fiber articles, such as half-sphere, cylinders, shells, etc.

In partial replacement of asbestos by fine (up to 15%) and superfine (up to 5%) BF in production of asbestos-cement products, the bending strength increases by 40%.

Thermal insulation using BF in machinery facilitates substantial saving in resources and simultaneous intensification of technological processes, which is especially significant in view of the potential energy crisis. In particular, through covering the surface of drying drums at cement factories (surface area 1 m^2; temperature about 250°C) by panels 40 mm thick based on superfine BF, the heat loss is decreased by 3000 kJ and the gas consumption is reduced by 8.4 m^3 per day, with the production efficiency increasing by 10 – 15% due to the accelerated drying process. Owing to that method, the annual gas saving in Ukraine amounts to 2.7 mln m^3.

Thus, the use of BF in the construction and power industries produces a substantial economic effect. The use of basalt fiber materials in construction makes it possible to decrease the weight of buildings and structures, decrease heat losses via external walls, diminish the noise level, and improve the comfort level of the interiors. The use of these materials, which are resistant to aggressive media, is especially advisable in the construction of agricultural and chemical facilities and cattle-breeding farms, where fiberglass and mineral wool heat insulators soon become brittle and get destroyed.

Figure 1 represents the scheme of producing fine staple BF, mats based on these fibers, and panels employing binders, and Fig. 2 represents the scheme of roving production based continuous BF. Figures 3 and 4 show the principal units in the production technology of smooth basalt plastic rods and basalt plastic fittings based on roving and environmentally safe binders. The production of continuous fibers involves jet and spinneret feeders made of a platinum-rhodium alloy and a filament collector for winding the fiber on the drum, which distinguishes the production of this variety

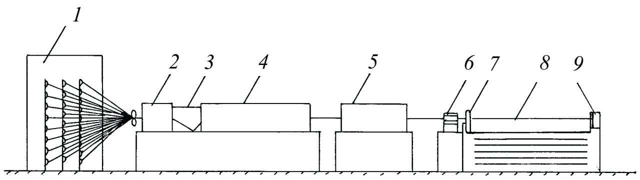

Fig. 3. Scheme of producing smooth basalt plastic rods: *1*) spool holder with roving spools; *2*) electric furnace for removal of moisture and lubricant; *3*) tank with the binder; *4*) spinneret; *5*) electric furnace for polymerization of coating; *6*) truck pulling device; *7*) disc saw; *8*) warehouse; *9*) saw end trigger.

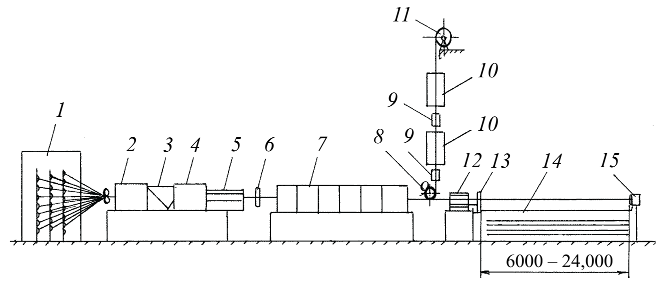

Fig. 4. Scheme of producing basalt plastic fittings: *1*) spool holder with roving spools; *2*) electric furnace for removal of moisture and lubricant; *3*) tank with the binder; *4*) electric furnace for removing volatile components from the binder; *5*) spinneret unit; *6*) winder; *7*) electric furnace for polymerization of the binder; *8*) rotary disk; *9*) vertical tanks for applying film coating; *10*) electric furnace for polymerization of coating; *11*) drum pulling device; *12*) truck pulling device; *13*) disc saw; *14*) warehouse; *15*) disc saw end trigger.

of BF from staple BF technology. The common element in the technologies of staple and continuous BF is the use of a melting tank furnace. There are various methods for preheating and melting the initial material (ballast gravel) in the melting furnace, based on direct electrical heating, combustion of gas, or liquid mazut fuel.

The economic efficiency of BF technology is determined by a number of factors. The first of them is the low cost of the raw material. Furthermore, as distinct from fiberglass production, the production of fiber from basalt gravel does not require additional modification of the batch preparation process and does not need balls or beveling planes, which significantly decreases the energy consumption. The use of the single-component basalt material also decreases the labor consumption. This technology does not require batch grinding and mixing divisions, nor the use of costly and scarcely accessible materials for batch improvement, such as soda ash, boron-containing materials, and fractionated slag. The service scheme of the technological process is simplified. The production of fine or thick staple BF does not require platinum-rhodium alloy feeders. It is sufficient to use air or steam blowing technology.

Feasibility studies were carried out for the basalt from the Myandukha and Kondopoga deposits, with respect to setting up the production of staple BF and panels in the amount of 50,000 m^3 per year, continuous BF roving in the amount of 300 tons per year, and basalt plastic fittings in the amount of 300 tons per year. The calculation results are shown in Table 3.

With the profitability of each type of production around 45%, the repayment period of the investment is around 2 years after reaching the design capacity. The capital investments were not taken into account in the calculations, as they are determined by the specific volumes of the required building and installation works, availability of premises, transport communications, and energy carriers, which form the production infrastructure. The current expenses include the cost of the production technology, its adaptation and adjustment to the local conditions, and the cost of materials, machines, parts, and wages. In estimating the sales revenues from selling basalt plastic fittings, 1 ton of basalt plastic fitting was taken to be equivalent to 10 tons of metal fittings. In making the cost analysis, the market situation was analyzed, as well as existent competitors and consumers.

In particular, it was established that the need of Arhhangelsk Region in heat-insulating material is 120,000 m^3 per year, whereas the main suppliers are located outside the region. The quality of supplied basalt fiber products (wool; mats) is low. The production of continuous BF, roving, and fabric does not exist. Therefore, the risk of setting up a production facility for BF and BF-based product in Russia is assessed as minimal. First, this is related to the shortage of domestic construction materials that meet the requirements of the new Construction Norms and Regulations. Second, the increased demands for environmental safety and heat and energy savings in buildings determine a demand for basalt fiber products. Finally, taking into account the advantages of the developed technical solutions (including the replacement of

TABLE 3

Product	Annual production volume	Current expenses, thousand USD (not including capital investments)	Time frame of reaching design capacity, years	Selling price per product unit, USD	Profit with 45% profitability, thousand USD	Repayment, years
Staple BF, mats, and panels	50,000 m^3	466	1.5	10/m^3	225	2.1
Continuous BF, roving	300 tons	1918	1.5	9/kg	1215	1.6
Basalt plastic fittings	300 tons	356	1.0	2333/ton	315	1.1

costly platinum-rhodium feeders and selection of environmentally pure binders), it is possible to expect exports of new universal materials and products with improved physiochemical parameters, whose production cost is lower than that of similar products based on other materials.

In order to reduce the capital construction costs, it is expedient to use the most ready production facilities. They are, as a rule, uncompleted production shops, ferroconcrete works, brick factories, etc.

The above technical and economical considerations suggest that the production of basalt fiber articles has high economic efficiency. There are available designs and technologies for staple and continuous BF, as well as products based on these fibers: broached mats, panels, roving, cords, cables, fabric, plastics, cardboard, paper, etc. These basalt fiber materials can be widely used in construction; power industry, agriculture, metallurgy, aircraft- and shipbuilding, electrical and radio engineering, and medicine.